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DETERIORATION OF WIND-THROWN TIMBER ON THE OLYMPIC PENINSULA, WASH.

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CONTENTS

	Page		Page
Introduction	1	Condition in 1926—Continued.	
Condition in 1921	3	Amount of losses	7
Condition in 1922	3	Comparative losses	18
Condition in 1923	4	Losses by areas	20
Condition in 1924	5	Rate of deterioration	23
Condition in 1926	5	Fungi causing decay	24
Method of study	5	Summary	27

INTRODUCTION

On January 29, 1921, a windstorm of extraordinary violence, apparently originating off the coast of Oregon, swept inland in a northeasterly direction between the mouth of the Columbia River and the west coast of Vancouver Island. On the Olympic Peninsula in the State of Washington, the damaged area comprised a strip 60 miles long and extending inland to a width of 15 to 20 miles or even more. At North Head, on the southwest corner of the peninsula, the wind attained a recorded velocity of over 140 miles per hour before the instrument was wrecked. Rains, heavy even for this region of high precipitation, preceded the storm. At Forks, in the northwest portion of the peninsula and in the heart of the storm zone, there was a rainfall of 23.73 inches during December, 1920, and of 29.70 inches during January, 1921. On January 29 the rain gauge was damaged by the storm and did not catch the rain. For the year from September 8, 1920, to September 7, 1921, inclusive, the rainfall amounted to 152.37 inches. The mean December precipitation is 18.13 inches; January, 19.49 inches; and annual, 122.34 inches.[1]

The heavy rains made the soil so soft and loose that a windfall without a known parallel in the world resulted. The dense, mixed stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), silver

[1] U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU. SUMMARY OF THE CLIMATOLOGICAL DATA FOR THE UNITED STATES, BY SECTIONS. WESTERN WASHINGTON. U. S. Dept. Agr., Weather Bur. Bul. W, p. 5, 1924. (Reprint sec. 19.)

fir (*Abies amabilis* (Loud.) Forbes), and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) occupying the low-lying country near the coast suffered most severely. There the trees were completely blown down over extensive areas. These trees, with their heavy crowns, shallow root systems, and habit of growing in dense stands through which the wind could pass with difficulty, were very susceptible to wind throw. Douglas fir (*Pseudotsuga taxifolia* (Lam.) Brit.) was not so badly wind thrown as the preceding species, since the so-called fir belt is near the eastern edge of the storm, where the wind was less violent. Furthermore, this species is deeper rooted and grows in stands more open than the preceding. In the Douglas fir type, areas on which the trees were completely leveled were relatively small, at the most comprising just a few acres, while generally only part of the trees in the stand were wind thrown. Western red cedars (*Thuja plicata* D. Don), with their lighter crowns, shorter boles, and deeper root systems, classed with Douglas firs in their resistance to windfall. Both young second growth and virgin overmature stands suffered, second-growth western hemlock in particular being severely damaged.

Plate 1 shows the effect of the storm on such a stand. The condition of the timber after the storm was appalling. Huge trees up to 6 feet in diameter breast high had been uprooted, and tangled masses of roots, soil, and rocks reared 15 to 40 feet in the air. Large trees with red-brown butt rot caused by the velvet-top fungus (*Polyporus schweinitzii* Fr.) were not uprooted but were usually broken off with a splintering break 6 to 15 feet or more above the ground level. Normally, the down trees were lying in one general direction in any one area, but in occasional places they were crisscrossed and twisted into a churned-up mass, indicating that the storm was partially cyclonic in character.

The actual quantity of timber that was wind thrown will never be known, since the storm-swept zone was never completely cruised. It has been variously estimated as 3.5 to 9.5 billion feet board measure, or 0.6 to 1.6 billion cubic feet. The true figure lies somewhere between and is probably closer to the lower than to the higher estimate. A partial cruise [2] of that portion of the wind-swept area within the Olympic National Forest, most of which lies along the eastern limits of the storm where the damage was not so severe, showed the following percentages by board-foot volume of the various species down: Western hemlock, 18.9; silver fir, 16.7; Sitka spruce, 9.8; Douglas fir, 6.1; western red cedar, 6.2; all species, 14.4.

Evidences of previous windfalls are not lacking in this region. On December 5, 1923, another storm in the same general region blew down about 125 million feet board measure over an area approximately 8 miles wide by 25 miles long.

Immediately after the catastrophe of 1921 the most important question that arose in connection with possible salvage operations was the rate of deterioration of this down timber. Unfortunately, no direct information was available. European forestry literature abounds with references to windfall, particularly in the Alps, but with the intensive utilization prevalent there, salvage operations are

[2] CONOVER, C. J. DESCRIPTIVE REPORT AND COST REPORT OF THE NORTHWEST END PROJECT, OLYMPIC BLOW-DOWN AREA, OLYMPIC NATIONAL FOREST. U. S. Forest Service, Portland, Oreg. 1921. [Unpublished manuscript.]

carried through so rapidly that the timber has little chance to deteriorate, and then, too, different species of much smaller size are invariably involved. It was known from the occasional windfalls encountered on logging operations in western Washington that western hemlock, silver fir, and Sitka spruce would decay rather rapidly, 2 to 5 years being the time estimated for these species to become unmerchantable, while western red cedar, except for the sapwood, which decays readily, would last indefinitely. Douglas fir was known to be very durable, trees that had been down 25 to 30 years still containing considerable merchantable volume.

In view of the enormous quantity of timber involved, the years that must elapse before it could be reached by logging operations, and the possibility of future windfalls in the same region, it was considered advisable to study the rate of deterioration of the down trees. The locality around Forks, in Clallam County, which was in the heart of the wind-swept area and climatically and silviculturally characteristic of the storm zone as a whole, was selected for the work. Except in 1925, yearly observations were made there at the end of August or in early September, beginning with the summer following the storm, and from June to September, 1926, a party of three men made detailed measurements of the down trees. During the seasons of general observations, 1921 to 1924, inclusive, no data were obtained on silver fir and western red cedar, because of the inaccessibility of down trees of these species. It was not considered worth the increased cost to investigate them, since the durability of western red cedar was well known and it was reasonably certain that silver fir would be comparable to western hemlock.

CONDITION IN 1921

The locality around Forks was first visited on August 27 to 29, 1921. At that time there was no decay in any species. Douglas fir was free from sap stain except where the trees had been cut in clearing out roads and trails, and then on the sapwood of the sawed ends there was usually a heavy blue stain, which, however, did not penetrate to a depth of more than 1 inch. There was some blue stain in a few trees that had been attacked by ambrosia beetles. Western hemlock sapwood was occasionally slightly blue stained, but in the few trees attacked by ambrosia beetles the staining was intense. Sitka spruce was intermediate between the Douglas fir and western hemlock in beetle infestation and staining. On Sitka spruce and western hemlock the common beetles were *Gnathotrichus sulcatus* Lec.[3] and *Trypodendron cavifrons* Mannh. The last-named species occurred also on Douglas fir.

CONDITION IN 1922

The timber was again examined on August 30 and 31, 1922. The Douglas fir had deteriorated little. There had been a slight increase in the infestation of ambrosia beetles, confined to the sapwood. An occasional tree without beetle infestation was slightly blue stained. On the places where the bark had been knocked off in falling, either very superficial and slight decay or injury by flat-headed borers

[3] The writer is indebted to J. M. Swaine, of the entomological branch, Department of Agriculture, Dominion of Canada, for the identification of these insects.

(Buprestidae) was occasionally encountered. Of the western hemlocks examined one tree was found with decay caused by the red-belt fungus (*Fomes pinicola* (Fr.) Cke.) just starting on the upper side of the trunk. The sapwood of some trees that were heavily attacked by ambrosia beetles was badly blue stained. But practically all the trees were free from decay, although most of them were slightly blue stained. Fewer trees of Sitka spruce than of western hemlock were blue stained, and the stain was not so deep. At this time there was no checking, and the actual loss in saw timber, except for the breakage in falling, amounted to little.

CONDITION IN 1923

The third examination of this timber was made on August 14 to 17, 1923. Sixty Douglas firs from 48 to 80 inches in diameter breast high that had been opened up by woodcutters were found to be sound, with one exception. This tree, 61 inches in diameter breast high, had the sapwood decayed to a depth of 1.7 inches on the top one-fourth of the circumference and for a lineal distance of 90 feet. This would result in very slight loss in merchantability, since the affected portion would slab out when sawed. The sapwood of about 15 per cent by number of the trees was infested with ambrosia beetles. Blue stain was not found except in the sapwood attacked by ambrosia beetles, and even then the stain was confined to the vicinity of the insect galleries. Fungous mycelium was not uncommon between the bark and the wood. The bark was just beginning to slip.

Of 40 western hemlocks, which were somewhat smaller than the Douglas firs, 90 per cent by number were heavily infested by ambrosia beetles and blue stained throughout the sapwood. Fifty per cent by number of these trees showed the early stages of decay on the upper sides of their trunks, extending to a depth of not more than 1.5 inches, but this would result in very little loss in merchantable volume, since the decayed portion would mostly go into slabs when the trees were sawed.

Thirty Sitka spruces of the same general size as the Douglas firs were examined. These trees were in the same general condition as the western hemlocks except that only 60 per cent by number were infested with ambrosia beetles, while 25 per cent showed superficial decay on the upper sides of the trunks. One tree was decayed by the shelf fungus (*Fomes applanatus* (Pers.) Wallr.) to a depth of 3 inches over a very small area where the bark had been knocked off when the tree blew down.

The sapwood of every tree of the three species examined was very moist and checking had not begun. The thick bark of these large trees afforded excellent protection against the sun during the short dry season in summer.

A stand of second-growth hemlock, completely wind thrown, presented a different condition. The trees varying from 13 to 30 inches in diameter breast high, with an average of 21 inches, were losing their bark, and the wood was checking severely, particularly in the smaller trees. The wood was very hard and would be difficult to saw. The red-belt fungus was commonly causing sap rot in the tops. The loss in this second-growth stand had already amounted to at least 25 to 50 per cent by board-foot volume, based on examina-

A COMPLETELY WIND-THROWN STAND OF YOUNG WESTERN HEMLOCK

Diameters breast high range from 13 to 30 inches

tions of some trees cut into log lengths near a small sawmill. The loss was mostly due to checking, but it was estimated that in two or three years this stand would be economically worthless, the remaining timber being destroyed by decay. The more rapid deterioration of this stand is explained by the fact that these smaller trees have thinner bark, which dries out and slips off relatively soon, exposing the wood to checking and rapid attack by wood-destroying fungi, which find in the wood adjacent to the checks a favorable balance of air and moisture.

CONDITION IN 1924

When the timber was examined again on August 7 and 8, 1924, there was abundant evidence that decay was beginning in earnest. Sapwood of western hemlock, Sitka spruce, and Douglas fir was commonly affected. The red-belt fungus and the shelf fungus were responsible for most of the decay, while *Lenzites sepiaria* (Wulf.) Fr., *Polystictus abietinus* (Dicks.) Fr., *P. versicolor* (L.) Fr., and *Stereum rugisporum* (E. and E.) Burt were also at work. The decay, confined to the sapwood, was most extensive on the sides and upper surfaces of the down trees, while there was little or no decay on the under surfaces where the wood retained for a longer time its high moisture content and consequent lessened supply of oxygen, together with a probable lower average temperature. This freedom from decay was particularly true of those trunks resting on the ground.

CONDITION IN 1926

METHOD OF STUDY

It had been originally planned to make careful measurements of the exact amount of deterioration of this timber during the summer of 1925, but emergency work prevented this until 1926, five seasons after the windfall had occurred, when a party of three worked from June to September measuring down trees [4] in the vicinity of Forks, where the previous observations had been made.

Where possible, down trees that had been cut into log lengths on logging operations were measured, but since there was very little logging under way in the down timber, it was necessary for the field party themselves to open up most of the trees sufficiently for examination and measurement. This was done by chopping into the trees at definite intervals, corresponding to the log lengths, until sound wood was reached. In measuring a tree the height above the former ground level at which it was possible to make the first saw cut was determined and became the stump height. The first and second logs were each measured as 16.3 feet, but the other logs were measured in as nearly uniform lengths as possible (with 32 feet plus the trimming allowance of 0.5 foot fixed as the maximum log length, in accordance with Forest Service practice in this region), depending on the broken sections in the tree and the point on the bole at which the 8-inch diameter inside bark was reached, this being the fixed merchantable limit decided upon. Beyond this diameter the bole was considered as top and one lineal measurement taken. The first two log measurements were made at 16.3-foot intervals in order to

[4] Earl G. Mason, of the school of forestry, Oregon State Agricultural College, was in charge of taking these measurements, and the writer is indebted to him for the efficient conduct of the work.

reduce as much as possible the error in figuring cubic volume caused by the butt swell. At each log length the average diameter inside bark, together with the average thickness of the bark, sapwood, and decayed wood, was determined. Where possible diameter measurements were made with a tape; otherwise calipers were used. All measurements were taken to the nearest tenth. Notes were also made on the kind and character of the decay.

In computing cubic-foot volumes, the entire tree from ground level to tip was included; the stump was considered as a cylinder, each log as the frustum of a paraboloid, applying the Smalian formula,[5] and the top as a cone. In those trees in which the top had been broken off previous to the windfall, that is, stag-headed trees, the section beyond the 8-inch diameter inside bark was treated as the frustum of a paraboloid instead of as the frustum of a cone, since it was found that the slightly increased volume given by the first formula was a negligible difference based on the total volume of the tree, and volumes by this formula were so much more quickly computed than by the formula for the frustum of a cone. In determining the board-foot volumes of the trees, that portion of the bole lying between stump height and a fixed top diameter of 8 inches inside bark was considered as merchantable. The logs were measured in board feet by the Scribner Decimal C rule.

When this timber was blown down the trees were piled on top of one another, and huge mounds of earth around the butt torn up by the roots were not uncommon. As a result of this it was impossible to cut most of the trees at the normal stump height, and long stumps were the rule rather than the exception, occasioning considerable waste. This waste was figured by the following method: It was found on logging operations in this locality that a stump 4 feet high, halfway on the slope, was about the average when standing timber was felled. This was fixed as the stump height, and greater heights were considered as waste. If an 8-foot stump section had to be left, 4 feet of this was computed as stump and 4 feet as waste. In cubic-foot volume this was done by treating the entire 8 feet as a cylinder with the top diameter for both sections taken at the 8-foot mark. There is, of course, a slight error introduced by this method, since the taper is not allowed for; but the additional work involved in eliminating this error was not considered justified by the purpose of this study. In board-foot volume this 4 feet of waste was not scaled independently, because such a method would give too high a value, but it was added to the length of the butt log, and the waste considered as the difference between the actual scale of the butt log as cut and the scale including this waste section. For example, a butt log 16.3 feet long with an average top diameter inside bark of 52.4 inches would scale as a 52-inch 16-foot log containing 2,020 feet board measure. Adding the 4 feet of waste, the log would be 20 feet long, containing 2,530 board feet which, minus the actual loss, 510 board feet would be 2,020 board feet.

The two other sources of loss in this timber were breakage in falling, and decay. Only decay occurring subsequent to the windfall was considered. Fortunately, the standing timber in this region is

[5] $(B+b)\frac{h}{2}$, in which B = basal area of the large end of the log in square feet, b = basal area of the small end in square feet, and h = length of the log in feet.

relatively sound. Decay in the down timber began in the outer sapwood and worked in, so it was easy to separate this from the decays present in the trees when they were living, since such decays were practically confined to the central portion of the heartwood. Furthermore, as will be shown later, the Indian paint fungus (*Echinodontium tinctorium* E. and E.), the velvet-top fungus (*Polyporus schweinitzii*), the ring-scale fungus (*Trametes pini* (Thore) Fr.), the quinine fungus (*Fomes laricis* (Jacq.) Murr.), and the rose-colored Fomes (*F. roseus* (A. and S.) Cke.) attacking the heartwood of the living trees were rarely associated with the decays working from the sapwood into the heartwood of the down trees.

In board feet the amount of decay was figured in relation to the amount of timber broken in falling and lost in the stump. The amount of the two last-named losses was first scaled for each tree and the amount of decay determined for the remaining merchantable volume. In cubic feet the decay was considered independently of the two other causes of loss, that is, the amount of decay in the breaks and the long stumps was also figured. This was done so that figures expressing the exact amount of decay in relation to the entire volume of the trees could be obtained. Consequently, in the subsequent discussion and tables where the total loss figures for cubic feet are given, these are slightly higher than actual, since a portion of the loss in breakage and long stumps is also included under decay. This is not important from a practical standpoint, since cubic-foot measure is theoretical, and the lumber industry in this region uses only board-foot measure.

Wind-thrown trees were studied on 12 different plots in the general vicinity of Forks. Measurements were distributed by species as indicated in Table 1.

TABLE 1.—*Species, number, and volume of trees studied*

Species	Number	Volume	
		Cubic feet	Board feet
Western hemlock	173	31,963	175,240
Silver fir	100	26,906	151,440
Sitka spruce	135	88,761	549,940
Douglas fir	112	91,962	599,020
Western red cedar	49	18,165	97,660
Total	569	257,757	1,573,300

AMOUNT OF LOSSES

Since this study dealt with the rate of deterioration of dead, down timber, it was apparent that the age of the trees when wind thrown would not be related to the rate of deterioration except in so far as age correlated with size, but that diameter breast high would be most closely related to deterioration. This had been brought out by a previous study on western yellow pine,[6] in which it was clearly indicated that the larger trees deteriorated more slowly. Consequently the following data are arranged by 4-inch diameter classes.

[6] BOYCE, J. S. THE DETERIORATION OF FELLED WESTERN YELLOW PINE ON INSECT-CONTROL PROJECTS. U. S. Dept. Agr. Bul. 1140: 3. 1923.

LOSSES IN WESTERN RED CEDAR

In Table 2 the loss in cubic-foot and board-foot volume is summarized for western red cedar from the two plots on which this species occurred. There was not sufficient basis of trees to show any difference between the plots, and because of the uniform conditions on them it is highly doubtful whether any differences other than those attributable to size would have been brought out by a larger basis. This holds also for the other species.

TABLE 2.—*Loss in wind-thrown western red cedar, in 1926, five years after windfall*

Diameter breast high (inches)		Average height (feet)	Average volume per tree		Percentage of average volume—								Number of trees (basis)
					Broken in falling		Lost in stump		Decayed		Sapwood		
Class	Average		Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
14	14.8	82.1	123	37.4	0	0	0	0	32.4	20.1	27.0	21.6	3
18	16.3	72.4	60	33.7	0	0	0	0	16.7	16.7	16.7	13.0	1
22	22.2	99.6	335	93.1	2.2	3.7	0	0	22.0	14.6	27.6	19.1	4
26	24.8	99.4	390	106.1	0	0	1.3	1.3	24.4	13.5	23.2	14.6	4
30	30.2	114.0	690	158.2	1.0	1.5	10.1	8.9	17.6	14.2	19.3	13.6	3
34	33.8	125.1	1,060	233.2	7.4	6.6	2.7	2.4	18.9	11.4	18.0	13.0	8
38	38.5	132.9	1,210	257.5	2.8	3.3	4.4	4.6	20.4	12.0	16.7	13.6	6
42	41.9	137.7	1,908	380.0	6.6	8.5	1.5	1.8	16.6	9.8	16.4	11.5	6
46	45.0	144.6	2,540	480.8	0	0	0	0	15.8	11.5	17.7	12.5	1
50	49.6	145.7	3,262	587.6	9.9	10.2	4.3	4.6	8.6	6.8	9.2	8.0	5
54	54.0	-------	3,510	611.7	9.4	9.8	8.0	7.8	14.4	9.7	10.7	8.2	2
58	59.4	142.7	5,030	879.1	7.2	6.0	7.4	7.3	6.6	7.4	5.7	7.4	1
62	62.0	-------	7,190	1,087.9	10.4	8.5	3.3	3.6	7.7	5.7	6.5	5.8	2
66	65.2	-------	5,860	972.5	51.0	32.9	1.7	.1	2.6	4.1	5.8	4.6	1
70	69.2	166.7	6,965	1,193.6	12.1	11.6	7.7	9.2	5.2	4.9	5.3	4.9	2
Average or total	38.4	123.2	1,993	370.7	10.7	9.1	4.3	4.4	11.6	8.5	11.1	9.3	49

The loss caused by breakage when the trees were wind thrown amounted to 10.7 per cent and 9.1 per cent of the total volume in board and cubic feet, respectively. The smaller trees showed less loss from this cause than the larger, as was to be expected. The amount lost in the stump was also greater in the higher diameter classes as a whole. This loss was 4.3 per cent in board feet and 4.4 per cent in cubic feet.

Decay up to that time had caused a loss of 11.6 per cent in board feet and 8.5 per cent in cubic feet. There was a very marked and fairly regular decrease in the percentage of decay with the increase in diameter in both board and cubic feet. In order to bring out the relation of decay to sapwood, the percentages of sapwood in board and cubic feet were figured. A slight error was introduced in computing the volume of sapwood. In the tops, beyond the 8-inch diameter inside bark, the heartwood was considered as a cone extending from that point to the tip of the tree, whereas in reality the heartwood ends at varying distances between these two points. This resulted in a lower-than-actual figure for the amount of sapwood in the top, but with trees of the size studied this error is insignificant, and it was not considered worth the time necessary in the field to determine the point at which the heartwood ended in order to eliminate this error. As with decay, there was a fairly regular decrease

in the percentage of sapwood with the increase in diameter. The amount of decay and of sapwood correspond very closely, the total of the former being 0.5 per cent higher than the sapwood in board feet and 0.8 per cent lower in cubic feet. The figures in cubic feet are more accurate, since volume computations in this medium can be relatively exact, while the unavoidable inaccuracies inherent in the computations of board-foot volume are too well known to necessitate discussion here. These figures show that in 1926 not all the sapwood of western red cedar had been affected by decay.

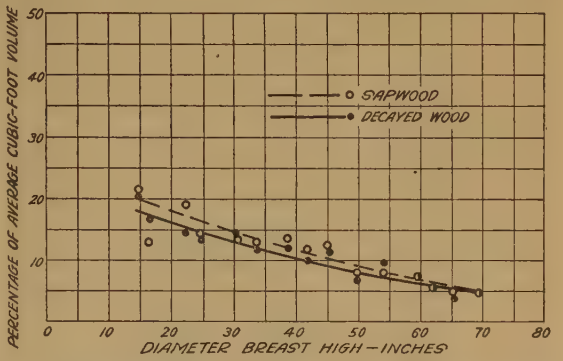

FIG. 1.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in western red cedar, based on volume in cubic feet

This relation between decayed wood and sapwood was more apparent when the data were plotted and curves drawn. Figure 1 shows the relation between decay and sapwood in cubic feet. The two curves have practically the same form, the volume of decayed wood being slightly less than that of sapwood except in the higher diameters, where the two coincide. In Figures 2 and 3, curves of the same data in board feet are shown. The curves of sapwood and decayed wood had to be presented as separate figures, since they practically coincide.

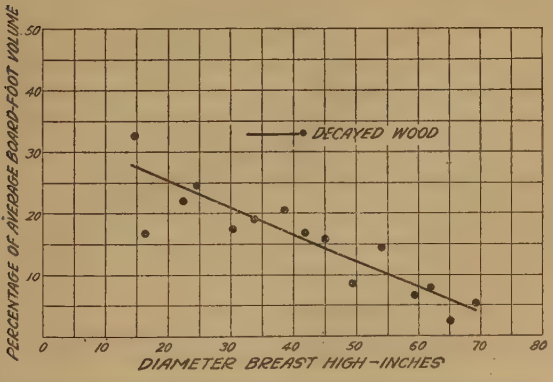

FIG. 2.—Diagrammatic smoothed curve illustrating the percentages of decay in western red cedar, based on volume in board feet

The total loss in these 49 dead and down trees, including breakage in falling, loss in stump, and decay, was 26.6 per cent in board feet. However, these percentages were higher than the actual losses in the cedar windfalls, since some of the down trees were still living. This is explained by the fact that the roots of some of the wind-thrown trees were not entirely broken off or pulled out of the ground and were covered with loose dirt. While the tops were broken off and dead, there were enough living limbs on the upper sides of the trunks to keep the trees alive. All the limbs on the under sides of the trunks were dead. On the two plots with the 49 down dead trees, there were in addition 11 down trees, or 18.3 per cent, still living. Detailed measurements on 3 of these trees, which were respectively 31.5, 34.1, and 35.8 inches in

diameter breast high, showed no loss of any kind in 2 of them and a slight loss from decay and breakage in falling in the largest, amounting to 1.1 per cent and 1.7 per cent of the total board-foot volume of the 3 trees and 1 per cent and 3 per cent of the total cubic-foot volume. Decay attacked dead portions of the sapwood connected with dead limbs, dead roots, or broken-off tops. On the underside of these living trees it was noticed that the annual rings put on since the trees had fallen were much browner in color than normal. An examination of these rings showed them to be largely composed of compression wood, which so commonly forms in conifers in connection with eccentric growth. The rate of diameter growth was normal on two-thirds of the trees and decidedly slower on the remainder.

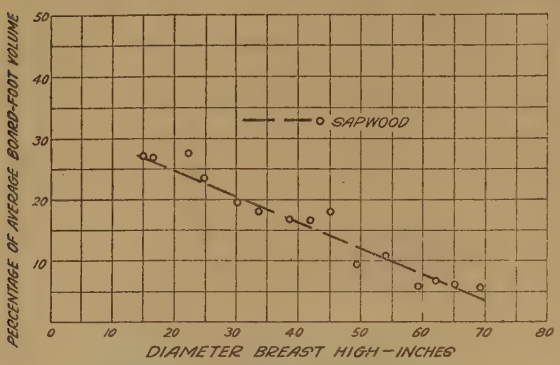

FIG. 3.—Diagrammatic smoothed curve illustrating the percentages of sapwood in western red cedar, based on volume in board feet

LOSSES IN DOUGLAS FIR

Table 3 summarizes the losses in cubic-foot and board-foot volume for the Douglas firs from the seven plots on which the species were represented. Here again in breakage in falling and loss in the stump in both board and cubic foot volume there is a greater loss in the higher diameters. The decrease in the relative amount of decay in both board-foot and cubic-foot volume with the increase in the size of the trees as indicated by the diameter breast high is very marked, and it is again noticeable that the loss in decay corresponds very closely to the amount of sapwood, the total being a little less in both units of volume. In Figures 4 and 5 is given the relation of decay and sapwood in board and cubic feet, showing that the percentage of decay is very close to the percentage of sapwood in the smaller trees, and thus indicating that decay would soon attack the heartwood. The combined loss from all causes amounted to 34.5 per cent of the board-foot volume.

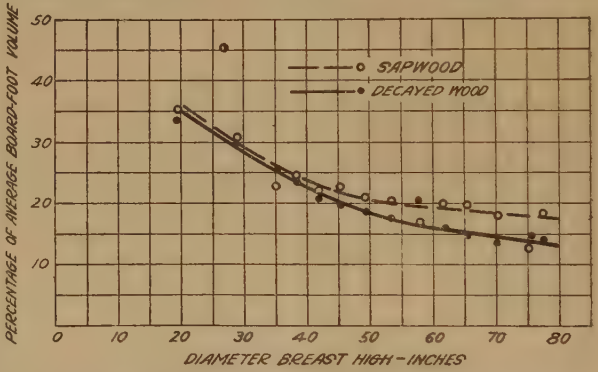

FIG. 4.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in Douglas fir, based on volume in board feet

It was noticeable that in some trees the sapwood, although apparently firm and sound, was discolored and was a decided pink. At

first it was thought that this might be the incipient stage of some decay, but later experience indicated that it was merely the leaching of the red-brown color from the very moist inner bark into the equally moist sapwood.

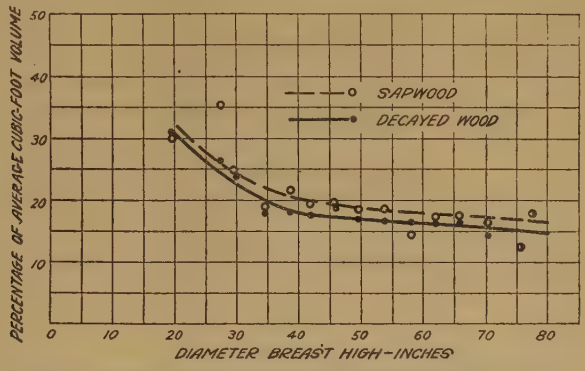

FIG. 5.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in Douglas fir, based on volume in cubic feet

TABLE 3.—*Loss in wind-thrown Douglas fir, in 1926, five years after windfall*

Diameter breast high (inches)		Average height (feet)	Average volume per tree		Percentage of average volume—								Number of trees (basis)
Class	Average		Board feet	Cubic feet	Broken in falling		Lost in Stump		Decayed		Sapwood		
					Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
18	19.7	155.3	540	118.8	5.6	5.7	0	0	33.3	30.8	35.2	29.3	1
22													
26	27.1	168.5	1,020	194.6	0	0	0	0	45.1	26.2	45.1	35.1	1
30	29.8	175.2	1,666	284.5	8.0	9.7	3.3	3.2	29.2	23.8	30.2	24.3	11
34	34.5	187.6	2,105	358.9	6.5	6.4	3.8	4.1	25.6	17.9	22.8	18.8	10
38	38.6	193.9	2,870	472.0	5.5	6.7	2.1	2.2	23.2	17.9	24.2	21.4	19
42	41.9	202.2	3,693	591.8	11.4	12.5	2.5	2.5	20.7	17.6	22.2	19.6	12
46	45.9	214.8	4,663	715.6	12.5	13.4	3.9	3.9	19.7	18.4	22.1	19.7	10
50	49.9	220.7	5,702	885.2	14.6	14.9	2.6	2.8	18.3	17.0	20.9	18.6	13
54	53.7	226.2	7,283	1,104.7	13.4	14.9	3.1	3.3	17.4	16.5	20.2	18.6	11
58	58.0	225.7	8,525	1,306.5	12.3	14.6	4.0	4.7	20.7	16.3	16.7	14.5	3
62	62.0	231.7	9,512	1,405.4	14.2	16.2	4.3	4.8	16.0	16.1	19.9	17.2	9
66	65.8	235.1	10,758	1,592.4	17.5	18.0	3.2	3.4	14.4	16.1	19.2	17.6	6
70	70.2	233.2	12,405	1,773.6	16.1	17.0	7.4	7.2	13.2	14.2	17.9	16.4	4
74	75.4	264.7	17,380	2,580.2	.4	1.4	1.0	1.0	14.3	12.3	12.5	12.4	1
78	77.5	232.1	15,630	2,248.2	15.7	17.6	7.7	7.1	13.8	17.8	17.8	17.8	1
Average or total	46.6	208.2	5,348	821.1	12.6	13.6	3.6	3.7	18.3	16.9	20.6	18.5	112

TABLE 4.—*Loss in wind-thrown Sitka spruce, in 1926, five years after windfall*

Diameter breast high (inches)		Average height (feet)	Average volume per tree		Percentage of average volume—						Number of trees (basis)	Trees with sapwood measurements					
					Broken in falling		Lost in stump		Decayed			Average diameter breast high (inches)	Average volume per tree		Sapwood (percentage of average volume)		Number of trees (basis)
Class	Average		Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet			Board feet	Cubic feet	Board feet	Cubic feet	
10	11.1	84.1	58	21.9	13.8	8.3	0	0	79.3	63.7	5						
14	14.5	111.7	178	49.9	0	0	1.9	1.8	87.5	67.4	9	14.9	190	55.6	63.2	44.3	1
18	18.0	117.4	335	80.5	1.6	1.7	1.5	1.4	85.2	66.4	14	17.3	252	68.2	45.7	42.9	3
22	22.2	130.1	566	125.8	2.9	2.8	3.0	2.6	76.9	59.7	11	22.6	530	119.7	50.0	37.0	2
26	26.0	146.0	1,030	203.2	9.5	8.5	.3	.2	65.9	57.0	11	25.7	1,123	214.2	30.3	25.1	3
30	30.2	177.1	1,529	276.0	8.4	9.9	1.7	1.9	59.4	52.2	7	29.8	1,730	310.9	35.3	28.2	3
34	33.1	173.0	2,106	362.8	.5	1.0	5.6	5.2	55.4	39.6	8	33.2	1,560	296.7	35.3	26.8	2
38	38.9	196.2	3,228	530.9	4.6	4.2	5.9	5.4	35.3	29.6	6	38.9	3,265	531.7	24.2	21.6	5
42	42.9	207.2	4,206	654.0	7.5	8.4	4.0	3.6	51.4	40.9	7	42.7	3,958	621.6	27.5	24.0	6
46	46.0	213.3	4,515	722.7	5.8	6.4	3.5	3.6	41.9	33.8	11	46.2	4,571	729.2	22.7	21.1	7
50	50.1	217.2	6,082	953.5	8.1	8.9	5.4	5.6	36.0	32.9	5	48.2	6,220	962.0	20.2	18.3	1
54	54.3	213.1	6,286	1,094.0	2.6	3.2	5.3	4.4	37.5	30.4	9	54.9	5,870	932.2	22.3	21.4	3
58	57.8	228.5	8,306	1,253.2	11.1	10.6	3.9	4.1	32.4	28.5	7	56.9	7,409	1,131.4	19.4	17.0	4
62	61.6	237.0	9,740	1,508.5	2.3	3.3	4.9	4.6	40.0	41.2	2						
66	66.1	232.8	9,859	1,486.8	4.0	4.7	4.4	4.3	29.1	25.6	11	66.2	9,746	1,462.7	18.1	16.3	7
70	70.4	211.3	6,250	1,047.7	2.5	2.9	6.6	7.5	44.6	35.6	3	71.8	7,830	1,309.4	23.0	20.7	1
74	75.4	221.8	10,420	1,571.9	2.6	2.7	3.7	5.2	23.3	25.6	1						
78	77.4	191.0	5,170	819.9	19.2	18.7	12.1	10.7	19.2	27.1	2	77.4	5,170	819.9	25.7	21.0	2
82	80.5	231.9	9,185	1,495.9	6.7	6.3	8.1	10.3	19.5	15.9	2	80.5	9,185	1,495.9	16.9	14.8	2
86	85.3	231.5	10,970	1,826.0	12.2	11.0	1.1	2.7	38.5	33.5	1						
90																	
94	95.0	231.1	16,260	2,943.7	3.3	3.8	1.9	1.5	11.4	7.7	1						
98																	
102	101.0	242.9	20,830	3,123.0	.3	1.1	6.5	6.4	14.8	12.7	1						
106																	
110																	
114																	
118	117.0	253.1	19,790	2,930.8	8.9	7.8	7.5	7.3	24.7	22.5	1	117.0	19,790	2,930.8	8.3	11.6	1
Average or total	40.6	177.4	4,066	657.6	5.7	5.9	4.7	4.6	35.9	31.2	135	47.7	4,977	784.1	20.9	19.1	53

LOSSES IN SITKA SPRUCE

Sitka spruce was found on 9 of the 12 plots, and the loss in this species is summarized in Table 4. There was a much greater range of diameter in this species than in any of the others. In general the same relations in the loss factors as found for the two preceding species held here, except that the increase in loss through breakage with the increase in diameter was not so apparent. The percentage of decayed wood was so high in the smaller diameter classes that the trees were no longer merchantable even though there was still a little sound wood in them. The total loss from all causes amounted to 46.3 per cent of the board-foot volume.

The measurements for percentage of sapwood are on a smaller basis of trees than the measurements of loss. This is because it was difficult to determine the limits of the sapwood of this species, many trees being so badly decayed and discolored that measurements were impossible. However, it is apparent that the percentage of decayed wood considerably exceeded the percentage of sapwood except in the 78-inch diameter class, showing that decay had already made severe inroads into the heartwood. This is brought out more plainly by figures 6 and 7. It was very noticeable that in trees with cracks the wood was invariably decayed to the depth of the cracks. This did not hold so consistently in the other species.

It is characteristic of Sitka spruce that the heartwood of some trees has a decided reddish or brownish pink color instead of the very light-reddish tinge which is just sufficient to distinguish it from the white sapwood. The cause of this color variation or the conditions under which it is produced have not been determined, but the field crew observed that heartwood of this deeper color seemed more resistant to decay than that normally colored. However, sufficient data on such trees were not obtained to prove this.

LOSSES IN SILVER FIR

Silver fir was studied on only the same two plots on which western red cedar was measured. The data are given in Table 5. Again, the same general relations of breakage in falling and loss in stump to diameter as found in the preceding species are in evidence here. The loss in decay, which amounted to a total of 62.6 per cent in board feet and 44.9 per cent in cubic feet, was very much greater than the percentage of sapwood. Decay and sapwood are compared in Figures 8 and 9. The heartwood of this species had been severely attacked. The total loss from all causes was 73.5 per cent of the board-foot volume.

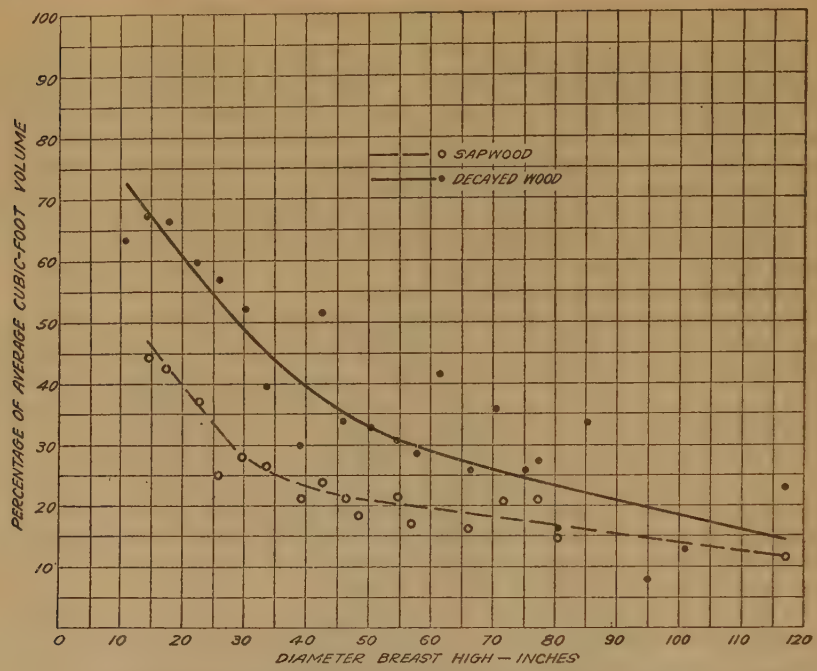

FIG. 6.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in Sitka spruce, based on volume in board feet

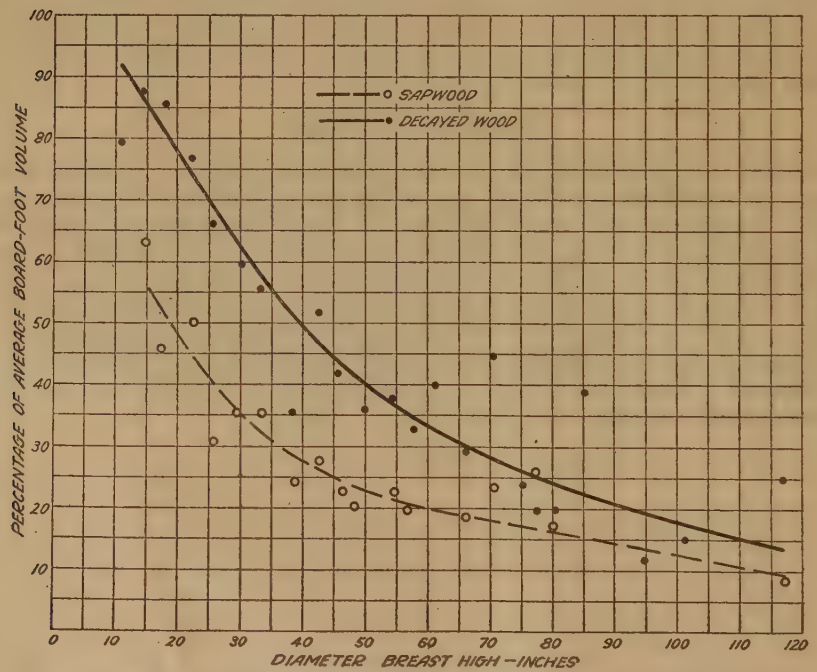

FIG. 7.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in Sitka spruce, based on volume in cubic feet

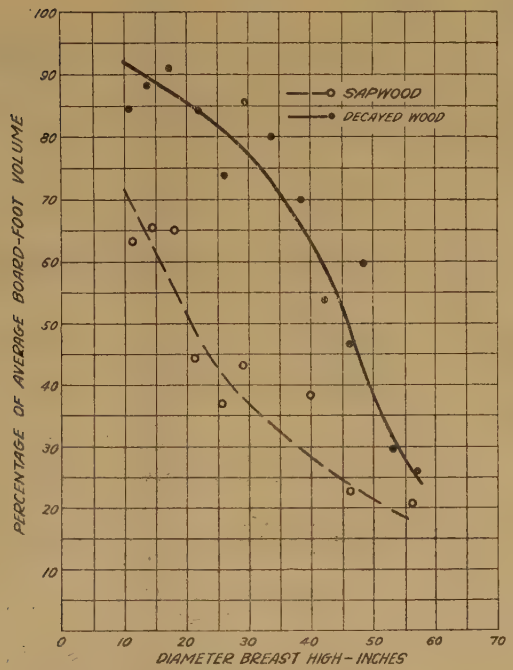

FIG. 8.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in silver fir, based on volume in board feet

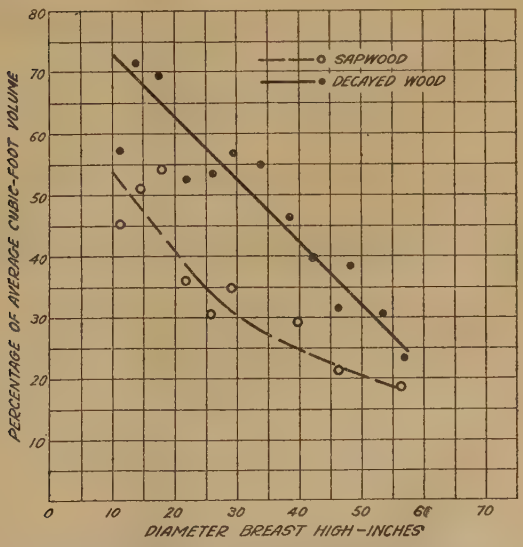

FIG. 9.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in silver fir, based on volume in cubic feet

TABLE 5.—*Loss in wind-thrown silver fir and western hemlock, in 1926, five years after windfall*

Diameter breast high (inches)		Average height (feet)	Average volume per tree		Percentage of average volume—						Number of trees (basis)	Trees with sapwood measurements					
					Broken in falling		Lost in stump		Decayed			Average diameter breast high (inches)	Average volume per tree		Sapwood (percentage of average volume)		Number of trees (basis)
Class	Average		Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet			Board feet	Cubic feet	Board feet	Cubic feet	
Silver fir																	
10	11.2	74.4	52	20.0	0	0	0	0	84.6	57.4	5	11.4	48	19.2	63.2	45.5	4
14	13.9	96.8	149	40.9	1.7	1.3	2.2	1.6	88.3	71.5	6	14.6	173	46.5	65.4	51.0	3
18	17.6	111.9	305	73.5	6.6	5.6	1.0	1.1	90.7	69.5	13	18.0	315	77.2	65.1	54.3	2
22	21.9	124.7	638	133.6	5.2	4.0	1.4	1.3	84.2	52.5	10	21.4	610	127.3	44.6	36.0	5
26	26.1	135.9	907	179.4	15.3	14.4	1.5	1.3	73.9	53.4	15	25.8	942	184.3	37.0	30.4	7
30	29.5	140.0	1,137	217.9	5.4	5.3	2.6	2.5	85.7	56.6	12	28.9	690	148.3	43.0	34.7	3
34	33.9	158.8	1,942	332.0	4.1	5.1	3.5	3.2	80.0	54.8	12						
38	38.5	162.2	2,332	406.9	9.0	8.3	1.4	1.6	69.4	46.1	11	39.8	2,340	410.1	38.2	29.4	2
42	42.1	165.4	3,132	513.8	7.5	6.0	1.4	2.0	53.8	39.8	3						
46	46.3	170.8	3,384	569.6	12.7	12.4	3.6	4.3	46.2	31.6	7	46.3	4,310	679.5	22.8	21.1	2
50	48.4	180.9	3,470	586.7	6.5	7.7	3.8	4.2	59.8	38.3	2						
54	53.2	183.6	5,312	847.4	10.1	12.5	2.2	3.1	29.1	30.4	2						
58	57.0	185.2	6,545	1,053.6	5.7	6.9	2.7	3.0	25.8	23.4	2						
Average or total	29.3	138.5	1,514	269.1	8.4	8.3	2.5	2.6	62.6	44.9	100	56.3	5,130	860.8	20.5	18.8	1
Western hemlock												25.1	1,086	199.4	32.9	28.6	29
10	10.6	85.0	61	21.7	6.4	4.2	0	0.6	84.4	70.1	9	10.7	74	25.9	66.1	53.1	4
14	14.4	120.4	230	57.0	15.1	12.0	.6	.3	80.5	68.8	20	13.8	184	45.5	82.2	63.8	7
18	18.1	136.4	498	103.3	9.3	9.4	1.0	.8	85.9	62.8	38	17.6	438	95.2	67.6	57.6	5
22	22.1	148.0	848	161.0	16.7	15.3	1.6	1.4	78.6	60.8	42	22.4	720	137.9	64.2	56.3	7
26	25.6	159.5	1,201	221.5	6.7	7.0	3.4	2.7	84.9	52.5	29	25.9	1,003	193.7	57.7	49.2	7
30	29.8	167.9	1,844	307.7	13.4	14.4	2.7	2.2	75.6	51.2	15	30.6	1,548	266.0	49.2	37.4	5
34	34.5	176.6	2,222	380.6	12.4	12.6	4.4	3.9	69.7	50.8	12	34.6	1,927	348.9	54.7	44.1	3
38	37.8	183.8	2,829	472.6	8.6	8.3	.8	.8	78.8	45.9	6	39.3	2,740	459.9	52.6	43.3	2
42																	
46	45.1	200.0	4,700	748.9	10.4	13.6	3.0	3.0	62.0	43.5	2						
Average or total	22.7	146.6	1,013	184.8	11.5	11.5	2.4	2.1	78.0	54.8	173	22.5	871	162.9	57.0	47.6	40

LOSSES IN WESTERN HEMLOCK

Table 5 gives the losses in western hemlock from the six plots on which this species was found. The loss of 11.5 per cent in both board-foot and cubic-foot volumes by breakage when the trees were blown down does not bear any apparent relation to the size of the trees in this species. The amount lost in the stump shows an increase with the increased diameter of the trees. Decay alone had already caused so much loss that the western hemlock for practical purposes was completely unmerchantable five seasons after it was wind thrown. The loss for all the trees amounted to 78 per cent of the board-foot volume, and even for the highest diameter class in which the loss was lowest it had reached 62 per cent. There was still a marked and fairly regular decrease in the percentage of decay as the diameter increased. This was most noticeable in cubic-foot volume.

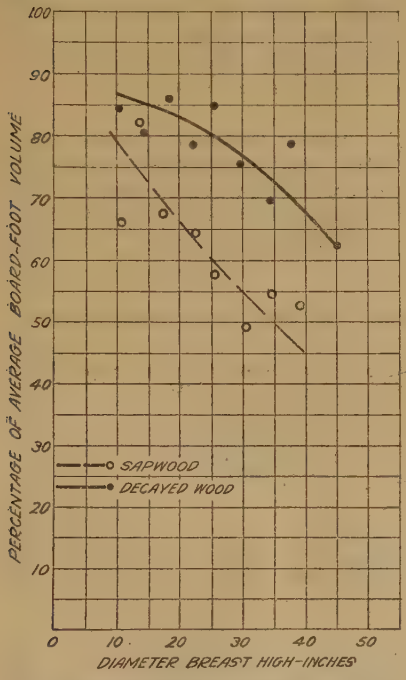

FIG. 10.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in western hemlock, based on volume in board feet

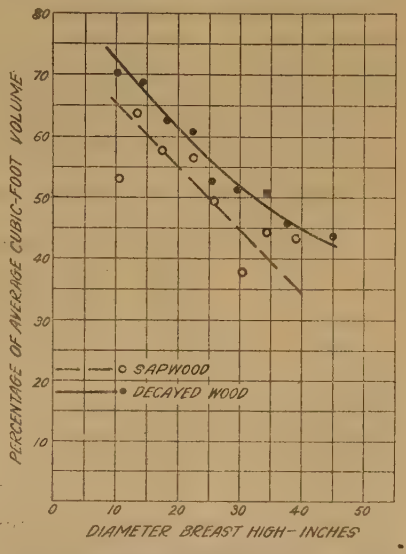

FIG. 11.—Diagrammatic smoothed curves illustrating the percentages of decay and sapwood in western hemlock, based on volume in cubic feet

The relation between decay and sapwood is brought out in Figures 10 and 11. These figures show clearly the heavy loss through decay and that considerable heartwood had been destroyed, particularly in the smaller trees. Sapwood in this species was extremely difficult to measure, and in many trees it was so badly decayed and discolored that measurements were impossible. In fact, it was thought that these figures for the percentage of sapwood might be too much of an approximation to be considered, so the curve for sapwood in Figure 11 was compared with a curve based on the sapwood of trees of the same diameter range on which measurements had been taken immediately after felling. The measurements on which this last curve was based

had been made many years ago by the United States Forest Service in the Puget Sound district of Washington. It was found that the percentage of sapwood as shown in Figure 11 averaged 5.8 per cent less, an allowable difference, since in a tolerant species like western hemlock two groups of trees with the same diameter range from different localities may differ considerably in age or degree of suppression, both of which materially affect the amount of sapwood.

The total loss in this species amounted to 91.9 per cent in board feet. All chance for salvaging western hemlock had passed.

COMPARATIVE LOSSES

The losses in the five species are compared in Table 6. This shows that there had been the smallest total loss in western red cedar and the greatest in western hemlock, with Douglas fir approaching the former and silver fir the latter, while Sitka spruce occupied an intermediate position. As was to be expected, this same relation holds for loss from decay, which was responsible for the major portion of the loss in each species.

The greatest losses in lost in stump occurred in those species represented by the largest trees; that is, Sitka spruce, western red cedar, and Douglas fir. Although Douglas fir had the largest average trees, western red cedar and Sitka spruce showed the greatest losses because of their excessively buttressed trunks. This loss was fixed in amount from the moment the trees fell.

TABLE 6.—*Loss in the five wind-thrown species, in 1926, five years after windfall*

Species	Average diameter breast high (inches)	Average height (feet)	Percentage of loss in board feet—				Percentage of loss in cubic feet—				Number of trees (basis)
			Broken in falling	Lost in stump	Decay	Total	Broken in falling	Lost in stump	Decay	Total	
Western red cedar	38.4	123.2	10.7	4.3	11.6	26.6	9.1	4.4	8.5	22.0	49
Douglas fir	46.6	208.2	12.6	3.6	18.3	34.5	13.6	3.7	16.9	34.2	112
Sitka spruce	40.6	177.4	5.7	4.7	35.9	46.3	5.9	4.6	31.2	41.7	135
Silver fir	29.3	138.5	8.4	2.5	62.6	73.5	8.3	2.6	44.9	55.8	100
Western hemlock	22.7	146.4	11.5	2.4	78.0	91.9	11.5	2.1	54.8	68.4	173

The other fixed loss from the time of falling, breakage in falling, may be influenced by chance, by the size of the trees, or by the inherent tensile strength of the wood of the different species. Size alone does not control this loss, because the heaviest breakage was in Douglas fir and western hemlock, respectively, the species having the largest and smallest average trees. The large amount of this loss in western red cedar and silver fir indicates that these species, also rather low in average volume, have wood of low strength. The strength of Sitka spruce, combined with its light weight, which makes the wood so suitable for airplane construction, is shown by the fact that while in size it was next to Douglas fir, it had the smallest percentage of loss due to breakage in falling.

TABLE 7.—*Percentage of decay and sapwood in all species, on basis of board feet*

[From curves in figs. 2, 3, 4, 6, 8, 10]

Diameter breast high (inches)	Western red cedar		Douglas fir		Sitka spruce		Silver fir		Western hemlock	
	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay
10							71.8	92.3	79.0	86.8
14	27.2	27.9				87.0	63.7	89.9	74.0	85.2
18	25.6	26.1			51.0	81.0	55.6	87.0	68.9	83.7
22	23.9	24.4	34.9	33.7	45.0	74.3	47.9	84.3	63.9	82.0
26	22.1	22.7	32.0	31.0	39.3	67.0	41.2	81.1	58.9	79.8
30	20.4	20.8	29.6	28.3	34.9	62.1	36.8	77.3	54.5	77.0
34	18.8	19.0	26.9	26.0	31.2	56.8	33.0	72.3	50.5	73.7
38	17.0	17.1	24.7	23.8	28.7	51.5	29.8	66.4	46.8	69.9
42	15.3	15.4	23.0	21.6	26.2	47.1	26.8	59.5		65.6
46	13.7	13.7	21.4	19.8	24.1	43.2	24.0	50.0		61.5
50	12.0	12.0	20.6	18.3	22.6	40.1	21.4	38.9		
54	10.1	10.3	19.9	17.1	21.3	37.5	19.1	29.9		
58	8.5	8.8	19.2	16.2	20.2	34.8		23.8		
62	6.9	7.1	18.8	15.4	19.3	32.4				
66	5.1	5.5	18.4	14.8	18.5	30.1				
70	3.3	3.9	18.1	14.1	17.7	28.2				
74			17.8	13.8	17.0	26.2				
78			17.5	13.2	16.2	24.7				
82					15.5	23.1				
86					14.7	21.9				
90					14.0	20.5				
94					13.3	19.3				
98					12.5	18.0				
102					11.9	17.0				
106					11.1	16.0				
110					10.3	15.0				
114					9.8	14.1				

TABLE 8.—*Percentage of decay and sapwood in all species, on basis of cubic feet*

[From curves in figs. 1, 5, 7, 9, 11]

Diameter breast high (inches)	Western red cedar		Douglas fir		Sitka spruce		Silver fir		Western hemlock	
	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay	Sap-wood	Decay
10							54.0	73.0	65.4	73.0
14	20.6	18.3			47.3	68.6	48.9	68.9	61.3	68.0
18	18.9	16.7			42.1	63.0	43.2	64.9	57.1	63.9
22	17.2	15.3	30.1	28.9	36.9	57.8	38.1	60.8	53.0	59.5
26	15.7	14.1	26.9	25.4	31.9	52.8	33.5	56.7	48.8	55.3
30	14.4	13.0	24.2	22.7	27.8	48.0	30.4	52.5	44.6	51.6
34	13.3	11.9	22.3	20.1	25.3	44.1	27.9	48.5	40.4	48.6
38	12.3	10.8	20.9	18.6	23.9	40.7	25.7	44.4	36.2	46.0
42	11.2	9.8	20.0	17.7	22.4	37.8	23.7	40.3		43.9
46	10.0	8.7	19.3	17.1	21.4	35.0	21.9	36.2		42.0
50	9.0	8.0	18.7	16.9	20.6	33.0	20.2	32.1		
54	8.0	7.2	18.1	16.6	20.0	31.0	18.8	28.0		
58	7.1	6.4	17.9	16.3	19.6	29.5				
62	6.2	5.8	17.7	16.0	19.0	28.2				
66	5.3	5.3	17.4	15.8	18.4	27.0				
70	4.9	5.0	17.1	15.4	17.8	25.7				
74			16.9	15.0	17.2	24.6				
78			16.6	14.7	16.8	23.5				
82					16.1	22.6				
86					15.6	21.5				
90					15.0	20.6				
94					14.4	19.6				
98					13.9	18.6				
102					13.4	17.7				
106					12.8	16.8				
110					12.3	15.8				
114					11.7	14.8				

The loss through decay was lowest in western red cedar and highest in western hemlock. But since it has been shown that the percentage of decayed wood is strongly influenced by the size of the affected trees, to get a true measure of the relative durability of these species it is necessary to compare trees of approximately equal size. Consequently the percentages of decay and sapwood in board and cubic feet have been read from the curves in Figures 1 to 11 and are given for all the species by 4-inch diameter classes in Tables 7 and 8, enabling a direct comparison to be made between the species at various diameters. It will be seen from these tables that all of the five species are represented in the diameter classes of from 22 to 46 inches. An average of the percentages of decay shown in Tables 7 and 8 within this diameter range is given in Table 9. This shows that western hemlock and silver fir, closely followed by Sitka spruce, were decidedly susceptible to decay, whereas Douglas fir and western red cedar were very resistant and would probably remain sound for many years.

TABLE 9.—*Average percentage of decay in all species*

[Diameter range from 22 to 46 inches]

Unit of measurement	Total volume				
	Western red cedar	Douglas fir	Sitka spruce	Silver fir	Western hemlock
Board feet	19.0	26.3	57.4	70.1	72.8
Cubic feet	11.9	21.5	45.2	48.5	49.6

LOSSES BY AREAS

To obtain an idea of the stand in this region and the losses resulting from the windfall, on 4 of the 12 plots studied all trees whether wind thrown or standing were measured, and the area of each plot was determined. The diameter at breast height of each standing tree was measured with a tape, its height taken with a hypsometer, and the board-foot and cubic-foot volumes calculated from taper curves. On 2 of the plots wind throw was complete, so there were no standing trees to estimate. The data on these plots, which are presented in Tables 10, 11, 12, and 13, need little comment other than pointing out the great loss from decay in second-growth hemlock as shown in Tables 10 and 12. On plot 8 (Table 11) it is seen that some of the standing trees had died since the windstorm. None of these dead trees was cut, so no figures were obtained on the loss through decay or other deterioration. This subsequent death of standing trees has been common throughout the storm zone, and all five species have suffered. An examination of some of the trees showed no evidence of insect or fungous attack that could have caused death, but the fact that the wind throw suddenly exposed these trees and that a very material change in site conditions must have resulted is sufficient to account for their death. Practically all the trees left standing had their tops broken out by the wind or by other trees falling against them, but in most cases the break occurred above or close to the merchantable diameter limit of 8 inches inside bark.

TABLE 10.—*Loss of timber, by species, on plot 1, in 1926*

[Area, 0.84 acre; completely wind thrown]

Species	Average diameter breast high (inches)	Average height (feet)	Volume per acre		Percentage of volume per acre—								Number of trees per acre
					Broken in falling		Lost in stump		Decayed		Total loss		
			Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
Western hemlock	22.1	132.2	42,140	8,051	9.7	9.8	0.1	0.1	79.9	54.6	89.7	64.5	52.2
Douglas fir	39.5	176.4	20,180	3,410	9.8	10.3	0	0	18.9	14.5	28.7	24.8	7.1
Sitka spruce	37.1	169.1	11,250	1,898	7.6	6.0	0	0	55.8	40.4	63.4	46.4	3.6
Average or total	24.9	134.3	73,570	13,359	9.4	9.4	.1	.1	59.5	42.3	68.9	51.8	62.9

TABLE 11.—*Loss of timber, by species, on plot 8, in 1926*

[Area, 1.7 acres; partially wind thrown]

Condition and species	Average diameter breast high (inches)	Average height (feet)	Volume per acre		Percentage of volume per acre—								Number of trees per acre
					Broken in falling		Lost in stump		Decayed		Total loss		
			Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
Down timber:													
Western hemlock	23.1	136.8	20,310	3,651	14.8	15.3	3.2	2.7	75.9	58.7	93.9	76.7	19.1
Douglas fir	56.1	213.5	87,020	13,130	12.9	13.8	3.5	3.5	17.9	17.1	34.4	34.4	11.6
Average or total	35.6	165.7	107,330	16,781	13.3	14.1	3.5	3.3	28.9	26.2	45.6	43.6	30.6
Standing live timber:													
Western hemlock	22.7	140.3	1,380	276	------	------	------	------	------	------	------	------	1.7
Douglas fir	57.4	197.8	18,660	2,909	------	------	------	------	------	------	------	------	2.9
Average or total	44.4	176.2	20,040	3,185	------	------	------	------	------	------	------	------	4.6
Standing dead timber:													
Western hemlock	37.2	110.5	2,490	388	------	------	------	------	------	------	------	------	1.2
Douglas fir	68.8	117.5	4,120	639	------	------	------	------	------	------	------	------	0.6
Average or total	47.7	112.8	6,610	1,027	------	------	------	------	------	------	------	------	1.7
Average or total for all groups	37.2	164.6	133,980	20,993	10.6	11.3	2.8	2.7	23.1	20.9	36.6	34.9	37.0

TABLE 12.—*Loss of timber, by species, on plot 10, in 1926*

[Area, 0.76 acre; completely wind thrown]

Species	Average diameter breast high (inches)	Average height (feet)	Volume per acre		Percentage of volume per acre—								Number of trees per acre
					Broken in falling		Lost in stump		Decayed		Total loss		
			Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
Western hemlock	21.1	153.8	80,820	15,018	12.3	11.2	2.2	1.8	81.3	56.3	95.9	69.3	92.1
Douglas fir	35.3	190.5	8,380	1,280	4.1	4.8	4.4	3.5	26.8	21.0	35.3	29.3	2.6
Sitka spruce	18.8	128.8	490	116	0	0	8.1	8.3	40.5	32.3	48.6	40.7	1.3
Average or total	21.4	154.5	89,690	16,414	11.5	10.6	2.5	2.0	76.0	53.3	90.0	66.0	96.0

TABLE 13.—*Loss of timber, by species, on plot 11, in 1926*

[Area, 1.11 acres; partially wind thrown]

Condition and species	Average diameter breast high (inches)	Average height (feet)	Volume per acre		Percentage of volume per acre—								Number of trees per acre
					Broken in falling		Lost in stump		Decayed		Total loss		
			Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	
Down timber:													
Western hemlock	29.4	169.3	33,660	5,836	9.0	10.1	4.0	3.5	74.8	48.8	87.7	62.4	17.1
Douglas fir	42.1	196.5	113,580	18,458	4.5	5.5	3.4	3.5	23.2	18.2	31.1	27.2	31.5
Sitka spruce	33.1	200.1	1,970	342	0	0	9.1	8.9	19.6	16.4	28.8	25.4	.9
Average or total	37.6	187.0	149,210	24,637	5.5	6.5	3.6	3.6	34.8	25.4	43.9	35.5	49.6
Standing live timber:													
Douglas fir	42.2	205.5	36,250	5,966	------	------	------	------	------	------	------	------	9.9
Western hemlock	26.6	125.0	1,780	330	------	------	------	------	------	------	------	------	1.8
Average or total	39.8	193.2	38,030	6,296	------	------	------	------	------	------	------	------	11.7
Average or total for both groups	38.0	185.4	187,250	30,933	4.4	5.2	2.9	2.9	27.7	20.2	35.0	28.3	61.3

In addition to the direct losses from decay, breakage in falling, and lost in stump, there are other losses that are more difficult to determine. It might seem that since the trees are already on the ground the cost of felling would be eliminated. One large logging company found that it actually cost 14 to 17 per cent more to log the down timber than the standing timber, and this increased cost was mostly chargeable to the greater difficulty of bucking. Many of the trees were merely held down by others lying on them and when released sprang back into a semiupright position. These badly leaning trunks then had to be felled, just like normal trees, and felling a leaning tree is difficult and expensive. The second factor adding to the cost was the awkward position from which many of the trees had to be bucked. Another cause of increased logging costs, harder to evaluate, is the smaller amount of merchantable volume obtained from a unit of area after the timber is partially or com-

pletely wind thrown, particularly if it has had several years to deteriorate. Finally, there must be some loss in the process of manufacture due to breaks not previously visible.

RATE OF DETERIORATION

Although the detailed study made in 1926 gives a good picture of the loss in the wind-thrown timber at that time, it is also of value to know the rate at which the timber deteriorated in the earlier years. As it was impossible to make yearly measurements on the scale of those of 1926, exact figures on the rate of deterioration in the earlier years can not be given. However, in 1923 it was found possible to examine a number of Douglas firs, Sitka spruces, and western hemlocks more carefully than in the other years and to obtain an approximation of the loss at that time. This examination showed that the sapwood of 15 per cent of the Douglas firs, of 60 per cent of the Sitka spruces, and of 90 per cent of the western hemlocks was blue stained and infested with ambrosia beetles and was therefore unmerchantable. Applying these percentages to the average percentages of sapwood in the trees of these species measured in 1926 gives the theoretical amount of deterioration in these same trees in 1923. As it is certain that deterioration had not begun in January, 1921, when the trees were blown down, the use of the theoretical figures for deterioration by 1923, and the actual figures in 1926, made it possible to plot curves of the percentages of deterioration in board feet and cubic feet for the years of exposure of the windfalls for the three species. The years were divided into months, so that the percentages of deterioration could be plotted for each of the two years to correspond with the time the data were obtained. Since the 1926 measurements extended over the period from the latter part of June to the early part of September, August 1 was taken as the average date for which to plot the deterioration. From these curves, which are not presented, Table 14, showing the percentages of loss through deterioration in board and cubic feet for each year on September 1, was constructed. To this loss through deterioration, which increases yearly, must be added the fixed loss by breakage in falling and loss in stump to determine the total loss in any one year. It must be emphasized that Table 14 is based on very meager data and an approximate figure for the amount of deterioration for one of the three points on which each curve was based. The figures should be taken as broad approximations.

TABLE 14.—*Rate of deterioration in Douglas fir, Sitka spruce, and western hemlock*

[From unpublished curves]

Year	Deterioration (percentage of total volume)					
	Douglas fir		Sitka spruce		Western hemlock	
	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet
1921	1.0	0.7	3.0	3.6	13.0	12.8
1922	1.8	1.5	7.5	7.3	32.0	30.5
1923	3.1	2.8	12.5	11.5	51.3	42.8
1924	7.0	6.5	20.2	17.5	64.5	49.5
1925	13.0	11.5	28.5	24.4	74.0	53.3
1926	18.8	17.5	36.5	32.0	78.2	55.0

From Table 14 it can be seen that western hemlock deteriorated much more rapidly than Sitka spruce in the first three years. This is explainable by the fact that western hemlock not only had a greater percentage of sapwood than Sitka spruce of the same size but also averaged much smaller, and that the relative amount of sapwood increases with the decrease in size of the trees; that is, the younger trees have higher percentages of sapwood. This sapwood, particularly in western hemlock, is very susceptible to ambrosia beetles and blue stain, which were responsible for the deterioration in the early years. The first marked evidences of decay were not apparent until 1923, and even at that time this defect was superficial. In 1924 decay was working strongly, and in 1926 the sapwood of all the species had been almost completely attacked, the decay more or less obliterating the evidences of blue stain and injury caused by ambrosia beetles. Douglas fir, with somewhat less sapwood than Sitka spruce, deteriorated much more slowly, since it did not prove to be so susceptible to stain and beetle attack.

The curves from which Table 14 was prepared were based on data so insufficient that it did not seem advisable to extend them in order to predict the future rate of deterioration. Western hemlock was completely unmerchantable in 1926. In Douglas fir the rate of deterioration will probably decrease, since the wood-destroying fungi must now decay the more resistant heartwood. In the case of Sitka spruce the fungi had already caused considerable decay in the heartwood and there had been no apparent decrease in the rate of decay, so it was a conservative estimate that in three or four more years the Sitka spruce would be completely unmerchantable, except very large individual trees. While silver fir and western red cedar were not included in the yearly observations, it can be stated, from the measurements made in 1926, that the rate of deterioration of the former will be very similar to that of western hemlock. Western red cedar, on the other hand, will deteriorate more slowly than Douglas fir.

FUNGI CAUSING DECAY

This enormous mass of down trees has formed a substratum for wood-destroying fungi, the like of which has never been known before. The principal deterrent to decay has been the heavy rainfall in this region, with the consequent high moisture content of the wood in the down trees. It was noticeable for the first few years, even at the end of the dry summers, that when the upper side of the trees was chopped into, water would frequently ooze out around the ax. It was not until the wood began to dry out a little that wood-destroying fungi were able to cause appreciable decay. Trees lying directly on the ground were sounder than those resting well above it, since the wood of the latter was drier. This fact is well known to the woodsmen cutting wind-thrown Sitka spruce into pulp bolts. Fungi attacking wood require a certain balance between air and moisture; an oversupply of either will inhibit their growth. Usually decay began on the top or upper portion of the sides of the prostrate trunks and then worked toward the under side, the wood there being slowest in drying out.

From Table 15 it can be seen that a number of different wood-destroying fungi were found attacking the trees studied, and an extensive survey of the entire windfall area would probably have

added more to this list. For example, *Poria subacida* Pers. was recorded on down Sitka spruce in this region prior to the windfall, and *Fomes spongiosus* (Pers.) Bres. was found on Douglas fir at the same time, but neither species was observed during this study. The trees of each species were first arranged by 4-inch diameter classes, but there was no apparent relation shown by this arrangement between size of the trees and species of fungi fruiting on them. It was not possible to make a count of the number of sporophores of each species without reducing the amount of other essential data obtained.

TABLE 15.—*Distribution of sporophores, by tree species*

Fungus	Percentage of trees of indicated species on which sporophores were found					
	Western red cedar	Douglas fir	Sitka spruce	Silver fir	Western hemlock	All species
Fomes pinicola		17.0	60.0	70.0	50.9	45.3
Fomes applanatus	4.1	25.9	11.9	49.0	24.9	24.4
Fomes annosus		1.8	8.9	16.0	2.3	6.0
Fomes roseus		.9	.7			.4
Polystictus abietinus		20.5	84.4	48.0	56.1	49.6
Polystictus versicolor	8.2	3.6	24.4	16.0	31.2	19.5
Polystictus cuneatus	22.4					1.9
Polyporus fibrillosus			8.9	9.0	1.7	3.7
Ganoderma oregonense				29.0	5.2	6.5
Lenzites sepiaria		12.5	33.3	6.0	56.6	28.6
Trametes pini			1.5			.4
Trametes heteromorpha					.6	.2
Stereum chailletii				1.0		.2
Stereum purpureum				1.0		.2
Poria cinerescens		.9				.2
Irpex sp				1.0		.2
Unknown		1.8			1.2	.7
Percentage of trees on which no sporophores were found	73.5	44.6	4.4	1.0	5.2	17.9

Sporophores of *Polysticus abietinus* occurred on the largest number of trees; those of *Fomes pinicola* were next most frequent in occurrence. Sitka spruce seems to be a particularly congenial host for the first-named species and silver fir for the last named. On the whole there is little evidence of host selection by the various fungi, except that sporophores of *P. cuneatus* Murr. were confined to western red cedar, while all the other species, except *F. applanatus* and *P. versicolor* on a few trees, avoided this host. *Ganoderma oregonense* Murr. was found only on silver fir and western hemlock. *Lenzites sepiaria* was most abundant on western hemlock and occurred sparingly on silver fir. *Polyporus fibrillosus* Karst. was not recorded on Douglas fir but was seen on it outside the plots studied. The other species, confined to one or two hosts, occurred on such a small percentage of trees that no significance can be attached to their distribution.

The fungi most abundant on these windfalls are of slight importance in causing decay of living conifers. *Fomes pinicola* occasionally infects badly wounded Sitka spruce, but the decay is usually confined to the wood immediately adjacent to the scar. It has been found attacking lowland white fir (*Abies grandis* Lindl.) in the same way, so it may probably attack silver fir. *F. roseus* frequently causes top rot in Douglas fir, but the resulting loss in merchantable volume is small. *Trametes pini* causes the most important decay of living Douglas fir and Sitka spruce, but on these windfalls it was found on

only two trees. *F. annosus* (Fr.) Cke., so severe in coniferous stands in Europe, is rarely found in this region except on old stumps or down logs. *F. applanatus*, a not-uncommon heartwood-destroying fungus on deciduous trees, has not been observed by the writer on living conifers in the Pacific Northwest. Unless the common fungi on these windfalls change their habits, they will rarely cause decay in the living trees of the remaining stand.

While a record of sporophores gives an idea of the relative abundance of the various fungi, the true measure of their importance is the amount of decay they caused. Although it would have been possible to obtain some knowledge of this by general observations, a closer estimate seemed desirable. Accordingly, measurements were so taken that the volume of decay caused by the various fungi could be computed as far as possible. (Table 16.) The resulting data, however, can not be considered more than approximations, but better, of course, than observations alone. In most logs several fungi were working, and it was impossible to evaluate the volume of decay caused by each. This accounts for the large percentage of decay listed as "mixed" in Table 16, and for the fact that despite sporophores of a certain fungus occurring on a tree species as is shown in Table 15, no loss from decay charged to the fungus may appear in Table 16. For example, Table 15 shows that 16 per cent of the silver firs had sporophores of *Polystictus versicolor;* yet there is no volume loss through decay shown for this fungus in Table 16, since the decayed wood could not be separated for purposes of measurement from decay caused by other fungi, so that it is included as "mixed." Then, too, it was difficult to identify many of the rots when there were no sporophores present, particularly when the decayed wood was in the incipient stage, which was very common with Douglas fir and western red cedar. For example, the decays caused by *Fomes pinicola* and *Polyporus fibrillosus* were very difficult to separate. Both fungi cause a brown carbonaceous decay, destroying the sapwood as well as the heartwood. Also the rots of *Ganoderma oregonense* and *F. applanatus* are very similar in their early stages. This difficulty in identifying decays without sporophores explains the large amount of decay listed as "unknown," particularly in Douglas fir and western red cedar.

The data in Table 16 were first arranged by 4-inch diameter classes for each tree species to see if there was any relation between the sizes of the trees and species of wood-destroying fungi attacking them, but none was indicated. *Fomes applanatus*, closely followed by *F. pinicola*, caused the most serious losses in Douglas fir and silver fir, while in western hemlock this order was reversed. In Sitka Spruce *F. pinicola* was by far the most important. These fungi caused deep decay, reaching into the heartwood as well as the sapwood. The other fungi were insignificant, and it is noteworthy that *Polystictus abietinus*, the sporophores of which occurred on the largest number of trees, was responsible for but little loss. This wood destroyer is usually confined to the outer one-half inch of sapwood. *Lenzites sepiaria*, which occurred on more trees than *F. applanatus*, caused but little decay. Practically all the decay in western red cedar was caused by *P. cuneatus*, with a little resulting from the work of *P. versicolor* and a trace from *F. applanatus*, which corresponds with the representation of sporophores on this host.

TABLE 16.—*Decay caused by the different species of fungi in trees of species shown*

Cause of decay	Percentage of total decay											
	Western red cedar		Douglas fir		Sitka spruce		Silver fir		Western hemlock		All species	
	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet
Unknown	83.5	82.0	52.3	52.9	10.3	11.6	2.9	5.5	9.4	10.3	18.7	20.4
Mixed	------	------	25.1	24.7	50.3	48.9	56.2	52.4	65.1	65.0	49.0	47.2
Fomes pinicola	------	------	6.2	7.0	29.8	28.4	16.8	15.6	10.7	9.7	17.5	16.9
Fomes applanatus	.6	.7	8.6	8.2	3.2	4.0	18.2	17.8	9.9	8.5	8.5	8.1
Fomes annosus	------	------	4.7	4.0	.2	.4	2.2	3.5	1.1	1.2	1.7	1.8
Fomes roseus	------	------	------	.1	------	------	------	------	------	------	------	------
Polystictus abietinus	------	------	1.3	1.6	4.8	4.8	3.0	4.6	1.4	2.4	2.8	3.5
Polystictus versicolor	2.8	2.8	.7	.5	------	------	------	------	.2	.3	.2	.2
Polystictus cuneatus	13.0	14.4	------	------	------	------	------	------	------	------	.3	.3
Polyporus fibrillosus	------	------	------	------	1.1	1.3	------	------	------	------	.4	.5
Ganoderma oregonense	------	------	------	------	------	------	.7	.6	.7	.5	.3	.2
Lenzites sepiaria	------	------	1.1	1.0	.3	.5	------	.1	1.4	2.0	.7	.9

SUMMARY

On January 29, 1921, a violent windstorm swept the west coast of the Olympic Peninsula, in the State of Washington, causing a windfall estimated at 3.5 to 9.5 billion feet board measure of western red cedar, Douglas fir, Sitka spruce, silver fir, and western hemlock. Beginning in the summer of 1921, observations were made yearly, except in 1925, on the deterioration of this down timber. In 1926 a careful study was made. It was found that western hemlock and silver fir had deteriorated very rapidly, followed by Sitka spruce, whereas Douglas fir and particularly western red cedar had deteriorated slowly. For the first three seasons most of the loss was occasioned by ambrosia beetles and blue stain in the sapwood. From the fourth season on, decay became important, so that by the summer of 1926 the sapwood of all species had been virtually destroyed and in addition considerable heartwood of Sitka spruce, silver fir, and western hemlock had been rotted. This was shown by comparing the percentages of decay and of sapwood, which were determined for each species. Decay was retarded by the high moisture content of the wood in the down trees, resulting from the normal heavy rainfall in the region.

In all, sporophores of 16 species of wood-destroying fungi were found on the wind-thrown trees. Only 3 species occurred on western red cedar, and 1 of these, *Polystictus cuneatus*, was confined to that host. Sporophores of *P. abietinus*, followed by those of *Fomes pinicola*, *Lenzites sepiaria*, and *F. applanatus* in the order named, occurred on the greater number of trees. However, the greatest total loss through decay was caused by *F. pinicola*, followed by *F. applanatus*. In western red cedar, however, *P. cuneatus* was responsible for most of the rot.

The total loss in the summer of 1926 in the trees studied, based on board-foot volume, had amounted to 26.6 per cent in western red cedar, to 34.5 per cent in Douglas fir, to 46.3 per cent in Sitka spruce, to 73.5 per cent in silver fir, and to 91.9 per cent in western hemlock. On the basis of cubic-foot volume, the total loss was 22 per cent in western red cedar, 34.2 per cent in Douglas fir, 41.7 per

cent in Sitka spruce, 55.8 per cent in silver fir, and 68.4 per cent in western hemlock. In addition to the loss caused by decay, this loss consisted of timber broken in falling and lost in stumps, which in many cases had to be left much longer than if the trees had been standing. However, except in western red cedar and Douglas fir, by far the most of the total loss had resulted from decay. From the standpoint of utilization, western hemlock and silver fir were already complete losses, and Sitka spruce, with the exception of the very large trees, would be so in three or four years more, whereas Douglas fir and western red cedar, especially the latter, would contain merchantable values for a long time.

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